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THE MICROSTRUCTURE OF SOME ALBERTA COALS

- by -

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A THESIS

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PREFACE AND ACKNOWLEDGMENTS.

The work described in this thesis was carried out at the University of Alberta, in part in the laboratories of the Mining Engineering Department, and in part in the laboratories of the Research Council of Alberta, under the immediate direction of Dr. A. E. Cameron, Professor of Metallurgy, to whom the writer desires to acknowledge his indebtedness for helpful suggestions and kindly criticism.

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C H A P T E R I.

HISTORICAL REVIEW

The study of the constitution and microstructure of coal is a comparatively modern subject. The following historical outline has, in part, been extracted from two papers, one by Stopes and Wheeler[1], and the other by Theissen[2]. The rest has been taken from the original papers, to which reference will be made.

The first reference to this subject in the literature was a paper by Karsten in 1826. Karsten described what he called "Faserkohle". He recognized it as being formed from plant tissues and attributed its origin to selective oxidation. He showed that the bright or "glanz" coal was higher in carbon than the dull or "matte" coal, but that the "faserkohle" was highest of all. Henry Witham, in 1832, succeeded in making thin sections. He showed what he thought to be cellular tissue but, since he also saw them in cannel coal, they must have been spore exines or spore coats. He concluded that coal was made up of alternate layers of cannel and coking coal. Goppert in 1840 studied Karsten's "faserkohle" or as he named it "charcoal". He stated that the structures seen were impressions and not true structure. His work was done on horizontal cleavages.

Bowman, in 1841, was the first to attempt to form a theory of origin. He noticed the laminations and endeavoured to translate their

meaning. He asks three questions which, however, he does not attempt to answer[3]. "Has that which contains more Hydrogen, because formed from resinous vegetables (the conifers) separated and arranged itself above others while in the fluid state, because its specific gravity was less? Does this laminar structure indicate that each thin layer, as it became bituminized, has been separately converted into 'coal' by a process commencing at the bottom of the mass and proceeding gradually upwards? Or, lastly, can it be reconciled with the simultaneous consolidation of the whole bed?"

In the light of present knowledge it can be readily understood that the first two could not be the case since pressure and heat are required for the formation of the coal. "Each thin layer" could not be coalified separately since, if the pressure was applied, there would be an unconformity, either due to folding in the case of a lateral pressure, or to sediment which would be necessary to cause vertical pressure being laid on top of each individual lamination. Thus, there must be "simultaneous consolidation of the whole bed".

Rogers, in 1843, noticed the finer laminae of bright coal in the dull coal. He concluded that the bright coal was pure and the dull, impure. John Quickett in 1853 studied cannel coal. He described cells and fibres but these have later been proven to be spore exines and layers of bright coal. Dawson (1859, 1866, 1871) explained and elaborated the subject of "charcoal" or as he called it "mineral charcoal". He attributed the compact coal to plant remains and the charcoal to a rotting of wood in the presence of air, in which it parted with its oxygen and hydrogen leaving a shell of carbon. This theory, somewhat modified, is held to the present day.

The period from 1859 to 1870 appears to have been an unproductive period in the study of coal, for no work of any note appears until the year 1870 when Huxley found that structure in the charcoal was more apparent than in the compact coal. Williamson made the same observation in the year 1881.

The next important worker was Von Gumble who, in 1884, recognized the triple structure of coal. That is, he divided it into "glanz coal", "matte coal", and"Faserkohle". These were his equivalents for bright coal, dull coal and mineral charcoal. He was the first to use maceration in the study of coal. He steeped the coal in an oxidizing agent, then removed the soluble parts with alkali. He found bark cells, cuticle and resin in the bright coal, and fibrous cells and pieces of cuticle in the dull. Wethered, in 1885, found that spores occurred in the dull coal but not in the bright. He stated that the bright coal was formed from vegetable tissues.

Seyler, who is one of the workers of note of the present day, presented his first paper in 1907. He stated that the bright coal was formed from woody tissue and leaves, was rich in carbon, poor in hydrogen, and had less volatile matter and ash than the dull coal. The dull coal was, in his opinion, the remains of leaves and cuticular tissue.

Stevenson, in 1911, substituted the French term "fusain" for mineral charcoal[4]. This term was not used until a later date.

James Lomax, in 1912, described the dull coal as consisting of megaspores (female spores) in a mass of microspores (male spores), and the bright coal as microspores in a ground mass of debris. He showed that even the brightest coals are laminated. Lomax followed this paper by another in 1914 in which he showed a number of photographs. These illustrated the presence of spores in the dull coal.

Theissen and White, in 1914, published what was probably the most detailed paper of the period[5]. They were the first to interpret the dull and bright bands. They showed that the bright coal had a conchoidal fracture, and stated that it was formed from stems. They described the dull coal as a mass of debris imbedded in a fine mud.

Edward Jeffrey published two papers[6] in 1914 and 1915. In these he determined three components of coal which he named charcoal, lignitoid (bright) and canneloid (dull).

Stopes and Wheeler, in 1918, published a monograph[7] in which they outlined the modes of origin of coal, its general constitution, action of solvents, distillation, and microscopical evidence of the constitution. They gave a very good review of the earlier work on the subject, and dealt with the constituents in great detail. The main body of the paper was devoted to the action of solvents and to destructive distillation.

Dr. Marie Stopes[8], in 1919, showed that there were four visible components in bituminous palaeozoic coal. For the equivalent of charcoal she used Stevenson's term "fusain" and coined three other names "vitrain", "clarain" and "durain" from Latin roots, making them conform to the term fusain. She described the vitrain as occurring as brilliant, narrow bands, unlaminated and with conchoidal fracture; clarain as a bright banded component, inherently laminated and breaking with a smooth surface; durain as dull and granular; fusain as a fibrous powdery, dark-colored substance. She stated that these terms applied only to British palaeozoic, bituminous coals.

Theissen, in 1920, published a paper[9] in which he described methods of preparation of samples, origin of peat, structures in coal, and a critical examination of three American seams. Theissen at this time

initiated the terminology still in use by American writers. The bright coal he found to be formed from wood tissues and thus he called it anthraxylon from anthrax - coal and xylon - wood. The dull coal he found to be formed from the debris of the peat so he called it attritus. The charcoal retained its name, mineral charcoal.

Stopes and Wheeler[10], in 1923, further defined the terms vitrain, clarain, durain, and fusain. Their paper was illustrated with plates showing the macroscopic and microscopic characteristics of these four components. In the same year they published a paper[11] on Spontaneous Combustion in which they included a historical review of the study of coal constitution.

Winter, in 1923, published a paper[12] on the study of coal by reflected light. This work was started about 1912 but was not published in English until 1923. He indicated his methods of polishing and etching, and showed some illustrations which he had obtained. He concluded from his investigations that coal was of a colloidal character. This paper started many workers studying coal by reflected light, and at the present time most investigators use this system.

Winter[13], in 1924, concluded that "Compared with bright coal, dull coal does not show cleavage but merely a more or less clear formation of layers. It is largely built up from spores, whilst these are less conspicuous in bright coal.

"The examination of banded coals has not yielded any result which is contrary to the present supposition that dull coal is sapropelic and bright coal humic (i.e. formed from humus)".

Turner,[14] in 1925, described his process of polishing and a process of flame etching. He gave a general description of the components of coal describing each one in detail. His nomenclature was the same as that of Theissen.

Seyler, in 1925, published a paper[15] called "The Microstructure of Coal" in which he described a new method of polishing, and a chromic acid method of etching. He outlined three methods of attack on the problem of interpretation:

"(1) Comparison of the structures observed in coals with those showing the various stages of disintegration of plants that are to be found in coal ball sections .....

"(2) The study of fossil stems, etc., in which part of the plant has become coal .....

"(3) The study in coal of the transition stages from well preserved structure to absence of structure ....."

Seyler favored the third method as being the most readily available.

Stach[16], in 1927, described yet another method of polishing. Instead of etching, he polished his specimens in relief, using alumina as the polishing media. This process will be described in detail later. He illustrated his paper with plates, showing fusain polished in this manner. The detail was very pronounced. He observed fusain in different states of preservation, and also the phenomena of fusain grading into vitrain. He concluded that "fusain was formed from wood, impregnated with ulmic substances, which has undergone a different process of coalification from the wood substance which became vitrain".

In the year 1928 Evans, in New Zealand, published a paper on the New Zealand lignites[17]. This is merely a description, macroscopically and microscopically, of the coal from a particular mine. He concluded that the deposit consists of transported material and was laid down under water.

Theissen and Francis[18], in 1929, attempted to correlate the British and American terminology. Their findings were, briefly, that anthraxylon is the same as vitrain, attritus the same as clarain, fusain the same as charcoal, while durain has no counterpart in American coals.

Evans, Slater, and Wheeler[19], in 1929, confirmed the findings of Stach, i.e. that fusain grades into vitrain. They used a modification of Seyler's method of etching.

Another innovation of that year was the process of etching with tetralin described by Iwasaki[20]. This process of etching requires from 20 minutes to an hour and a half, depending on the rank of the coal.

In 1930 Tideswell[21] gave a general review of the origin and components of coal. This paper is really a short summary of the facts known about coal at the present time.

Slater, Evans, and Eddy,[22] in 1930, classified the spore exines of the Parkgate seam and showed how spores might be used as a means of correlation of coal seams.

It can be seen that, at the beginning of the study of coal, very little could be done since the technique of making sections had not been perfected. Gradually the art was mastered, and the different components were examined. The first writers saw only two components, compact coal and charcoal, but soon three were recognized. There were many wrong conclusions drawn through failure to distinguish between the bright coal and the brilliant coal, causing much controversy as to the presence or absence of structure in the bright coal. This question was not cleared up until Dr. Stopes published her paper on the four components of coal. At the same time the American writers coined an altogether different terminology. This also caused diffi-

culty until these were correlated by Theissen and Francis in 1929. The thin section method was the only one used until 1924 when Winter initiated the polished section method. This has been used to a great extent from that time on, the only changes being in technique of polishing and etching.

Since the terms vitrain, clarain, and durain refer only to Palaeozoic bituminous coals, and since this work was done on Cretaceous coals the writer will use the terms anthraxylon and attritus in the discussion which follows. The American term "mineral charcoal" appears cumbersome and thus, for this component, the term "fusain" will be used.

C H A P T E R I I.

ORIGIN OF COAL.

Mode of origin.

The first theory of origin was that of formation by igneous intrusion into bituminous deposits. Later evidence has shown plant origin however, and a regular transition can be seen from peat, through lignites and bituminous coals, to anthracite. Since this fact has been firmly established, the only subject for controversy at the present time is the mode of deposition of a particular deposit. It is generally accepted now that there are two main modes of deposition - deposition in place, and deposition by migration and accumulation.

Deposition in Place.

Peat is formed in bogs, marshes, sloughs, or swamps. The name usually designates the type of flora. This may be trees, trees and shrubbery, shrubbery and grasses, or grasses alone.

Bogs are usually small areas, varying from a few inches to fifty feet deep. They begin as a small lake or pond surrounded by trees and shrubs. The plants around the border decay and fall into the water. When this has accumulated so as to reach the surface, the shrubs gradually shift out to this new land area. This process continues until the ground near the original margin of the lake becomes firm enough to support the growth of trees. Thus the grasses and shrubs, followed by the trees, creep towards the centre of the lake. The first trees are the conifers and these are followed by the

deciduous trees. The whole area finally becomes timbered and forms what is known as a grove.

Several zones can be seen when peat is examined. The peat near the bottom is dark and dense; that on top is light-colored and fibrous. The latter is formed from the trees which grew on the former. Sometimes trunks of trees can be seen but usually small chips are the only remnants. These chips are flat thin pieces, probably formed by exfoliation of the annual rings, or by splitting along the medullary rays. Dry-rot occurs in dry seasons, and a substance develops which later would be changed to fusain. In wet seasons the wood is better preserved and may be buried intact. This would form anthraxylon bands and the debris around it would form attritus.

Marshes are areas without trees. The deposits are usually small and shallow. The land surface is water-soaked but there is no open water. These conditions are not very favorable for peat formation.

Fresh-water swamps are, probably, the best conditions for the formation of coal. They are near base level and thus may be inundated causing the formation of seams. They are, also, of a size which would give rise to a considerable amount of coal. They usually have areas of open water. These would fill with spores and pollen grains and canneloid coal would result. Other areas are quite dry, and would be ideal for the formation of fusain. The flora of these swamps is pine in the higher parts and cypress, spruce, and juniper in the lower parts. Examples of this type of swamp are the Dismal Swamp in Virginia and the large swamps of Sumatra.

Another type of swamp, common in tropical regions, is the Mangrove swamp. This type usually occurs in salt or brackish water. They form along the coast in inlets, bays, and in areas of water which have been left by a retreat of the sea, or areas which are connected with the sea at

high tide and are isolated at low tide. The mangrove trees have long, stilt-like roots, which raise their trunks high above the water. Debris collects among these roots and eventually may form peat beds. This peat has sand and mud mixed with it by waves and tide. The areas are not extensive, and the rate of accumulation is too slow for the formation of much peat.

Deposition by Migration and Accumulation.

Some deltas have been found to contain low grade coals. As an example of this, lignite was found while drilling for water in Venice. This water was charged with hydrogen carbide and the wood was well enough preserved to be identified.

An enormous amount of timber drifts down a river in a year, especially if it flows through virgin forest. Since, however, the greatest amount of wood is transported during flood time when the rivers are saturated with mud, it would be almost an impossibility for pure coal to be formed in this way.

"In an effort to obtain definite information regarding the proportion of plant debris carried by streams and thus support his arguments for the drift theory for the basin of Commentry, central France, Fayol stretched a wire screen of one centimetre mesh across a stream known as the Baune. This was done in the month of January and it collected 502 grams in 2 minutes, or 1.5 grams for each cubic metre of water passed through. He also made certain laboratory experiments in a small body of water to determine the action of vegetal matter in sinking to the bottom and of mixing, or separating itself from the sediment which was carried into the body of standing water with the plant materials. He found that the roots were among the first materials to sink. Many stems remained in an upright or inclined

position on the bottom and the plant debris formed deposits from practically pure vegetal matter to those highly mixed with mineral matter" [23]

This last shows that there is a definite sorting action when sediment and vegetable matter are carried into a body of water.

In the Commentry area in France inverted tree trunks are found. Fish remains are also found in the coal of this area.

A sequence said to be proof of formation by drift is the sequence of conglomerate, sandstone, shale and coal. This is said to be an assortment due to specific gravity and rate of settling.

In order to make the necessary amount of peat to form fifty to sixty feet of anthracite the large trees would have to root in peat. Some say this is an impossibility.

A possible method of accumulation of peat is a formation such as the Sargasso Sea. The mass of plankton, or floating plants might be caught by eddies and thus form well preserved peat deposits. This would be formed of low types of plants and seaweed.

As a rule coal is relatively pure. This would indicate that it would not likely be formed in a place where mud and silt were being laid down at the same time. This would eliminate to a great extent such modes of formation as mangrove swamps, deltas, and rivers. Wood would not deposit in one place in the case of river transportation unless piled up on the shores of a lake or bay by tidal or shore currents. The sequence of conglomerate, sandstone, shale and coal might also show erosion towards base level and consequent lack of carrying power in stream currents. In fact coal could not form in seams if the region of deposition were not near base level. The matter of trees growing in a great mass of peat is not an impossibility since trees have been found which were specially equipped for

this particular environment. The Sargasso Sea has been investigated by dredging and very little accumulation could be found on the bottom. A great deal of plant material must be floating between the surface and the bottom, however, and this would be deposited by a gradually shallowing sea. Coal seams usually contain evidence of shallow water or land deposition in the presence of littoral deposits interbedded with the seams.

The writer would conclude that the great mass of coal has been formed by deposition in place, i.e. from swamps and bogs, but that small and, in most cases, impure, deposits might, and possibly have been, formed by migration or drift, and accumulation. There is also the possibility of formation by a combination of the two main modes of formation.

Rate of accumulation of peat and coal.

The rate of accumulation depends on the rate of growth and decay of the plants involved. The rate of growth depends on the type of vegetation and the rate of decay on the climate. Coarse vegetation accumulates, or at least builds, faster, but some small plants are more important in the formation of coal because of smaller shrinkage. Spores collect very quickly in open water. The soils also help in the accumulation because of differences which they cause in the rate and extent of growth. A steady climate induces a large growth and thus a large accumulation. The rate of decay in a warm climate is very great, but if the rainfall is large, and the debris is covered with water, this decay is off-set. No peat will be formed if there are long alternate wet and dry periods unless the weather is cool. The wood will all decay in the long dry periods if the weather is warm, but if it is cool the decay is delayed and the water has a chance to cover the wood with a protective sediment.

To quote Moore[24] "In summing up the data concerning the rate of

growth of peat Ashley states that under the most favorable conditions 1 foot may form in 5 years, and that 1 foot in 10 years is a fair average maximum ..... Lesquereaux considers that a foot of peat at the surface shrinks to 1/8 foot at depth in the bog".

Ashley[25] has calculated that 3 feet of old peat will form 1 foot of bituminous coal. Therefore if a foot of old peat forms in a century, it will require 3 centuries for the accumulation of material to form 1 foot of bituminous coal.

Transformation of vegetable material into coal.

It is generally recognized that when vegetation changes to coal it passes through two stages, the biochemical and the dynamochemical.

The Biochemical stage.

When plants in a swamp or bog cease to grow, they fall and are subjected to attack by bacteria and other organisms. Renault[26] has shown that a great many bacteria of the forms micrococcus and streptococcus have been sufficiently well preserved for their remains to be visible under the microscope. These were active at the surface of the swamps, but their influence did not extend to depth.

Fungi also tend to produce chemical change and maceration of plant debris. They break up the oxygenated hydrocarbons into simple oxides of carbon and liberate hydrogen ~~which~~ in the form of water and methane.

Bacterial action is stopped by the humic acids which the bacteria themselves form. It may also be stopped by burial under layers of sediment, or by a coating of mineral matter deposited from solution. Coal balls are formed in the latter manner.

The Dynamochemical stage.

The dynamochemical stage in the transformation of peat into coal is widely recognized and accepted. This stage comes after the bacteria have ceased to function due to burial of the plant-remains under layers of sediment. This sediment gradually increases in depth and thus in weight. The peat has a great deal of volatile matter. Some of this is driven off by the pressure and the harder and more compact brown coal or lignite is formed. This in turn, when subjected to more pressure, loses volatile matter and bituminous coal is formed. This would seem to be a simple hypothesis but when anthracite is considered it is found that it cannot be formed by pressure alone. Some other factors must come into play in the formation of anthracite. This has caused a great deal of controversy as to what single process will develop the different varieties of coal. Some of these processes are, differences in vegetation and climate, the length of time the vegetation was exposed before burial, the depth and time of burial, action of igneous intrusions, possibility of escape of volatile constituents, and the thrust-pressure hypothesis.

Differences in vegetation and climate.

Coals vary very little in their physical condition. They all contain bright and dull bands, spores, cuticle, and other debris. When woods are analyzed they are found to be so much alike in composition that it does not seem possible to obtain different types of coal from them. If different portions, such as spores, are isolated from the main part it seems conceivable that variations in coal types or varieties would be possible.

Exposure before burial.

If wood is exposed to air there is a selective rotting in which

the carbon increases and the oxygen and hydrogen decrease. The wood rots first, leaving the bark and related tissues. A striking example of this is the birch tree. One can often find a shell of bark still standing although the wood has all rotted away. Since fusain is considered to be formed from the products of this dry-rot which have been buried, while the rest of the coal is formed from a process of disintegration of the wood buried in its original state, it follows that there may be a considerable difference in variety due to the degree of exposure before burial. This will not explain the major differences in coal, however, since lignites, bituminous coals and anthracites all contain fusain.

Depth and length of time of burial.

Although it is recognized that fixed carbon increases and volatile matter decreases with depth, i.e. the coal rises in grade, it must be remembered that anthracite will not form by pressure alone. Other factors being equal, the older the coal the higher it will be in the peat to anthracite scale. Also, the older the coal the deeper it will normally be buried and thus the greater the pressure and heat to which it will be subjected. This is not always the case. There are some Carboniferous coals which are lignites and Cretaceous anthracites are found. Coal may form in a relatively short time providing the factors heat and pressure are favorable. This is proven by the fact that mine props subjected to pressure and mine fires have changed to a substance greatly resembling coal in the short space of thirty years.

Effects of igneous intrusions.

It has been proven beyond doubt that the heat of an igneous intrusion accompanied by the pressure it exerts will produce anthracite from

bituminous coal. Coals formed in this way have been found in Colorado, New Mexico and Alaska. The effects of igneous intrusions are quite local and do not extend much beyond the intrusion. Thus the effect of igneous intrusions, though real, is limited. It shows, however, that a combination of heat and pressure is capable of changing a high-grade bituminous coal to anthracite.

Possibility of escape of volatile constituents.

Since the amount of volatile matter, to a great extent, determines the grade of the coal, the ease with which these constituents escape will be a factor in the formation of different types of coal. In order to form coal the peat must be subjected to heat and pressure for a considerable length of time. If the cap rock is porous, or fractured enough to allow the slow escape of the volatile constituents the deposit will gradually pass through the different stages of lignites and bituminous coals. The stage at which the cap rock fractures ~~and~~ enough to relieve the pressure will determine the final grade of the coal. Anthracite will not usually be formed except in regions of intense folding and high temperature. In this case the cap rock, though porous, must withstand the pressure without too much fracturing.

The Thrust-Pressure Hypothesis.

Anthracite, as mentioned before, is usually found in regions of intense folding and high temperature. White[27] has worked out an hypothesis on this basis in which he states that thrust pressure is the most logical explanation of the devolatilization of coal. He shows that in almost all rock formations or series containing coal seams, there are found competent beds of sandstone and conglomerate and incompetent beds of shale and coal. When thrust pressure is applied the incompetent beds yield and adjust them-

selves to the movements of the competent beds. There is thus a shearing action, with the result that great pressure and heat is applied to the incompetent beds while the competent beds suffer very little.

From the above discussion it can be seen that many factors enter into the formation of a coal seam. It would be unfair to say that all seams were formed in the same way. A summary might make this statement clearer. If the peat were covered with enough sediment, the pressure might be great enough to form lignites or bituminous coals. In this case the cap rock would not tend to fracture to any great extent and the grade of the coal would depend simply on the porocity of the cap rock and the length of time and depth of burial. If this seam happened to be in a region of crustal disturbance and a shearing action was developed, as outlined in the thrust pressure hypothesis, this lignite or bituminous coal would form anthracite, providing the cap rock was porous and withstood the pressure for the length of time necessary for its formation. If the original coal was lignite, and the competent beds fractured during the process, the resultant coal would be of the bituminous variety. Anthracite might also be formed by an igneous intrusion into a bituminous deposit.

Thus it can be seen that it is impossible to define one process for the formation of all types of coal, and that all the factors which might enter into the case must be considered.

Origin of cannel and boghead coals.

These coals are formed in a different manner from the other coals. They usually occur as lens shaped layers in other coals. The cannel coal is found to be formed from microspore exines and other resistant parts of the plant. These apparently collected in open water and settled to the bottom.

The bogheads were originally supposed to have been formed from algae, in open water areas of the original peat bogs, but were later found to consist of megaspores suggesting an origin of the same type as that of cannel coal. Lately writers have tended to revert back to the algae theory.

C H A P T E R I I I.

COMPONENTS OF COAL.

Methods of Examination.

A specimen of coal may be examined microscopically, and its components determined, in two ways (a) by the use of transmitted light through thin sections, as is commonly employed in mineralogy and botanical studies, or (b) by the use of reflected light from a highly polished and properly etched surface as is universally employed in metallography. By the former method remnants of the plant tissue and of the organic coal-forming substances are distinguished by the relative translucency or opacity of the structure-forming material. In the latter method differentiation of component parts depends on the relative hardness of the various substances, their ability to take a polish, and principally perhaps to their relative resistance to the attack of the chemical etching solutions. The first method, when the sections are carefully selected and properly prepared, probably yields the most accurate results, giving clarity of definition and fineness of structural details comparable with those obtained in mineralogical and botanical studies. Preparation of the sections, however, is a laborious and painstaking undertaking which often is not warranted by the results obtained. The second method, although sacrificing some detail in structure to simplicity in preparation usually gives results with sufficient detail for most determinations, particularly when it is considered that the coalification processes have of necessity distorted or

destroyed the greater part of the fineness of detail of the original plant tissues and organs.

Preparation of sections.

Thin sections.

There are two methods of making thin sections (a) by grinding, and (b) by means of the microtome.

The grinding method as used by Theissen[28] consists in grinding the coal down with emery until a smooth face is obtained. This face is then ground on a hone. When the desired polish is obtained the specimen is mounted, face down, on a glass slide, with Canada Balsam, and the opposite side ground in the same way until the desired thickness is obtained. After a cover-glass has been cemented on, the slide is ready for use. The soft, friable nature of coal tends to cause breaking out of pieces, particularly during the final grinding to thickness and most slides so prepared have many holes in the section.

The microtome method is much simpler and easier, but there is danger of loss of some of the constituents of the coal through solution in the softening agent. Mineral matter in the shape of silica is first removed with hydrofluoric acid and the coal is then softened by boiling in an aqueous solution of caustic potash or in phenol. With very soft coals, boiling in a mixture of glycerine and water may suffice. The softening process may be combined with the demineralizing process by treating the coal alternately with hydrofluoric acid and the softening agent. Following demineralization and softening the coal is dehydrated, mounted in paraffin and sliced with the microtome. Once a specimen has been softened and otherwise prepared for slicing, a large number of thin sections may be obtained and a very exact determination of the structures made.

Polished sections.

Seyler's method may be taken as an example of the preparation of polished sections. "The polishing is done, according to metallurgical practice, by the use of a polishing machine and successively finer emery paper, followed by polishing on a cloth moistened with a suspension of levigated green oxide of chromium, and a final rubbing on 'selvyt' (a cotton velvet polishing cloth) moistened with alcohol"[29].

Such a procedure comparatively rapidly produces a highly polished flat surface which will reflect light well, but due to flowage of surface material is structureless except for the broader macroscopic differences in the coal substance. To develop the structure the flowed surface must be removed and structural details brought out by etching.

Etching.

Several different solutions have been advocated by different workers as suitable for etching the surface of polished sections. Schultze's solution (potassium chlorate in nitric acid) has been used but it is very violent in its action and is liable to cause cracking. Other solutions suggested are mostly mixtures of chromic and sulphuric acids.

The operation of etching is described by Seyler[30] as follows: "The sample is then etched by immersion in a boiling solution made by adding 10 c.c. of concentrated sulphuric acid to 30 c.c. of a saturated solution of chromic acid. The solution is boiled until chromic acid begins to separate and the polished sample is then immersed in the liquid, which is kept boiling for a few minutes. The sample is then removed, cooled, washed, dried, and very slightly rubbed on selvyt moistened with alcohol".

This method has been modified by Evans, Slater, and Wheeler[31].

Instead of boiling the etching solution during the process, the source of heat is removed before immersing the specimen. The specimen is then washed with boiling water, immersed in dilute sodium hydroxide, washed with cold water, and dried.

Besides etching with chemical solutions two other methods of bringing out the structures present in the polished section have been advocated - flame etching and relief polishing.

Flame etching has been perfected by Homer G. Turner[32]. He outlines the method as follows: "The specimen is placed in a drying oven .... and heated ..... to about 220°C ..... After this temperature has been maintained for about an hour the specimen is removed with warm forceps and the polished surface immediately brought to a red heat by applying the oxidizing blowpipe flame at right angles to the face. A differential oxidation is thus produced which reveals the structure without destroying the polish".

Relief polishing is discussed by Stach[33] as follows: "The surfaces of the coal are prepared in a manner similar to that used in preparing ore surfaces ..... When the polishing of the specimen has been carried through from the coarsest to the finest grade of alumina, and the surface is free from scratches, the surface is polished with a coarse alumina on a fresh polishing cloth ..... The details become still finer if the polishing is continued with alumina of medium grade, while polishing with fine alumina brings out the finest details of structure".

All of these methods of finishing the surface of the polished section bring out, through differential effect, irregularities in the polished surface, and if these irregularities are arranged in, more or less definite, regular or repeated patterns they are termed structures and may be correlated, with due allowance for compression, distortion, etc., with structures ob-

servable in normal plant tissues and organs. They may frequently be correlated with similar structures observable in peat.

Outline of Botanical Terminology.

Certain botanical terms must be used in any description of the components of coal, and it is considered advisable to give here an outline of the meaning of the more commonly employed terms. The term "cells" is of course common and needs no explanation. There are more than one type of cell but as far as possible they have all been grouped under the one general term. The space inside the cells, when preserved, is called the "lumen". The original division line between two cells is the "middle lamella" and a point where two cells have broken away from one another is called an "intercellular space". The "cuticle" is the "epidermis" or skin of a leaf or young twig. "Spores" are the reproductive organs of plants such as ferns, and their outside coats are called "spore exines". "Medullary rays" are lines of cells which radiate outwards from the centre of the stem. "Tracheids" are water-carrying cells.

Components of peat.

As peat was the fore-runner of all coal the structures and components of peat are of prime importance in the determination of the components of coal.

To the unaided eye peat appears as an amorphous pulpy mass, with chips ~~of wood~~ or even larger pieces *of wood* mixed with it. When viewed under the microscope, the pulpy mass is seen to be composed of particles recognizable as fragments of plant tissues and organs. There are whole cells, parts of cells, and complexes of cells as well as rootlets, leaves, bark, pollen grains, cuticle, spores, etc. If dry this mass would form a fine dust or attritus and is thus called the attritus by American authors.

The most readily recognizable components of peat are bits of wood and leaves. The woody parts grade in size from very minute pieces to whole logs or stumps.

Spores, pollen grains, resin and cuticle, although forming a small part of the whole, are very important in the formation of coal. The spores of the Pteridophytes have thick outer coats composed of a mixture of resin, waxes, oils and cutocellulose which are resistant to decay. The pollen grains of all plants have an exine of the same composition, but much thinner than that of the pteridophytes. The woody parts decompose and are lost, while the spore exines decay relatively little. This is also true of the cuticular tissue. All leaves and needles are covered with a membrane of a composition similar to that of the spore exines, and this is equally resistant to decay.

The resinous matter in peat bogs originates in various ways. Almost all conifers contain resin cells. Some contain reservoirs in which resinous matter is collected. Often these are so large that one tree may yield several gallons of resin. Flowering plants may also contain resin both in the wood and the bark. Resin is not subject to decay and is left behind when the resin-bearing tissues decay.

A small amount of the mass of the peat is in the amorphous condition. It is composed of plant matter that has been so macerated as to have lost all structure. ~~Some of the~~ This grades into larger particles, which show characteristics of the cells. They are poorly defined and ragged in appearance.

General components of coal and correlation of terminology.

All anthracite and bituminous coals, and ~~to~~ some ~~extent the~~ lignites, are found to be ~~more or less~~ laminated. The bands differ in such

characteristics as color, lustre fracture, and thickness. Usually very shiny black layers alternate with bright black or grey bands. Sheets of a substance resembling charcoal are found interbedded with these lamellae.

Dr. Marie Stopes, working with British palaeozoic bituminous coals, determined four principal constituents which she named Vitrain, Clarain, Durain and Fusain. Probably the best description of these is that given by Dr. Stopes[34].

"Fusain occurs chiefly as patches and wedges, somewhat flattened parallel to the bedding plane and often with rather square-cut ends. It consists of powdery, readily detachable, somewhat fibrous strands. The orientation of the fibrous structure tends to be lengthways in relation to each wedge, and the various wedges in a bedding plane lie at various angles to each other, so that in any given light some appear dull and some glisten, according to the direction the light catches the fibres .....

"Durain occurs generally as bands of variable thickness, and when seen in a face at right angles to the bedding plane they appear parallel to it, though if traced far enough they generally reveal their ultimately lenticular shape ..... Durain is hard, with a close firm texture, which appears rather granular even to the naked eye. However straight the break across it, the broken face is never truly smooth, but if looked at closely always has a fine lumpy or matt surface. Generally, even in the dullest of durain bands, a few (or many) flecks or hairlike streaks of bright coal are seen. The intercalation of narrow bands of clarain and durain tends to increase at the juncture of the broad dull and broad bright bands, so that there is no large surface of contact between them, which is sharp cut and well defined; even the purest clarain and purest durain tend to have ravelled edges which interlock[35].

"Clarain occurs generally as bands of very variable thickness, and when seen in a face at right angles to the bedding plant they appear horizontal to it. Like durain bands, they are ultimately widely extended lenticular masses. Clarain, even when considerably streaked with durain, has a definite and smooth surface when broken at right angles to the bedding plane, and these surfaces have a pronounced gloss or shine. This surface lustre is seen to be inherently banded, as well as to have fine bands of durain intercalated between its own bands.

"Vitrain occurs as definite rather narrow bands, sometimes straighter and flatter than the other bands of coal and sometimes more obviously lenticular. True brilliant vitrain bands are often markedly uniform in thickness for considerable distances and are commonly from one-eighth to one-fourth, but are seldom more than one-half inch thick ..... A single brilliant band does not exhibit the fine layering detectable even in the brightest of clarain, but is a coherent and uniform whole - brilliant, glossy, indeed vitreous in its texture. The compact vitreous bands may split up readily in the fingers to small cube-like segments, but more generally they break irregularly when forced, as with a pen knife point, when the curved irregular faces have a well-marked conchoidal fracture".

American coals have been described by Reinhardt Theissen[36] and Homer G. Turner[37]. To quote Theissen, (this follows a discussion of peat):

"Coal may now be examined with a clearer understanding of the terms and a more intelligent interpretation of the characters observed because, as the author believes, coal deposits and peat deposits have been formed in analogous ways, and because the constituents in coal and in peat are analogous in every respect, except that the plants that contributed to the deposit of each differed in kind, although not materially in cell

structure and chemical composition .....

"A bed or bank of any bituminous coal is readily seen to be laminated; likewise a block or lump of coal when examined more closely is seen to be composed of many layers or seams differing from one another in color, texture, fracture, degree of absorbing or reflecting light and differing greatly in thickness.

"A little study shows that in general there are two kinds of layers or striae. One is jetty black, and usually has a high lustre, reflects light readily, is more compact and breaks with a decidedly conchoidal fracture; the other is greyish black, has a dull appearance, and little or no lustre, does not reflect light as readily but rather refracts it, is less compact and breaks irregularly. The former is usually found as lenses of varying thicknesses and widths and on close examination is seen to be imbedded in the latter; this last characteristic is most evident in extensive exposures or in large blocks. Even with the naked eye, after a careful examination, the duller layers of striae are seen also to be composed of numerous thin alternating bright and dull sheets .....

"When coal is examined along cleavage surfaces parallel to the bedding planes, it is seen to contain charcoal, also called 'mother coal' or mineral charcoal, in thin layers or laminae. As the charcoal stands out prominently on the horizontal cleavage faces and is readily recognized, even when present only in small quantities or thin sheets, the earlier observers distinguished only two classes of coal - compact coal and charcoal.

"But when the coal is examined along the vertical cleavage surfaces only, the charcoal appears as dull coal, is overlooked, only dull and bright laminae being observed.

As regards types of components, ordinary bituminous coal may be said to have three, dull coal, bright coal and charcoal; but as regards differences in compactness or hardness, coal may be said to have two components, compact coal and charcoal, as described by the earlier investigators...

"The most prominent ..... are the broad black bands .... - the so-called 'bright coal', 'jet coal' or 'glanz coal' of other authors. These black bands are most always lenticular, or broad, flat pieces that have a wedge-shaped termination. The black bands run for some distance through a larger block or even a long distance through the coal in the seam before they terminate. In a small piece of coal they generally continue through the piece from one side to the other, and for that reason convey the idea of laminae or layers instead of inclusions, but it is not rare to find complete lenses or their edges in small blocks..... The bands of bright coal should therefore properly be called lenticular laminae. These lenticular laminae vary in thickness but are rarely more than 10 mm. or three-eighths of an inch thick ..... They correspond to the larger pieces of woody peat, such as pieces of logs or stems, branches, twigs and roots. Being definite pieces of coal derived from wood these components are called anthraxylon, meaning coal-wood, from anthrax- coal, and xylon - wood.

The characters that stand out next in prominence ..... are the lighter striated bands or layers between dark bands. These represent the so-called 'dull coal','Cannelloid coal', 'matte coal' of other investigators, because they have a dull look compared with the layers of 'bright coal'.

"This dull coal is composed of a general debris derived from a variety of plant products and corresponds to the general debris of peat deposits .....

"A more careful examination of the 'dull coal' shows that this

in turn is composed of many thin light and dull sheets ..... The brighter sublaminae are anthraxylon components ..... That part of the coal in which the smaller anthraxylon chips are imbedded, ... is finely divided matter and corresponds to the fine black 'mud' or attritus of peat, and ..... is similarly composed. This component of the coal will, therefore, be called attritus".

In 1929 an attempt was made by Theissen and Francis[38] to correlate the British and American terms. Their findings were as follows:

"Vitrain, the same as anthraxylen - brilliant bands with conchoidal fractures.

"Clarain, the same as attritus - the thin bright streaks in clarain are bright streaks of vitrain (anthraxylon), which can not be readily separated from the duller portions. Inherently laminated, it breaks sharply with a smooth surface at the break.

"Durain - a dull band granular coal; has no counterpart in American coals. It is difficult to break, and surfaces are always granular or matt. It is largely composed of opaque matter and spores in varying proportions.

* At a later date Theissen found that the "splint" coals found in parts of Kentucky and West Virginia were equivalent to the British durains. Thus the above description of durain must be modified to the effect that, although, as a whole, the American coals have no counterpart for durain, there are certain instances, as cited above, where this component may be found.

Theissen, R. Splint Coal - Classification of Coal. A. I. M. M. E. 1930, p. 79

'clarain' and 'durain' should only be used for coals of bituminous rank". *

Structures commonly found in coal.

Fragmented cells.

Cellular fragments of a characteristic shape and disposition

are found. The fragments are usually bounded by arcs and their linear disposition is often noticeable. This has been called "bogen-structure". This structure probably represents fractured secondary tissue. In some cases medullary rays are indicated which proves it to be wood.

Unfragmented cells.

Whole cells can often be seen. When the middle lamellae are filled by a dark matrix they are easily seen on etching and may be the most persistent feature of the survival of the coal. This also applies to the lumens.

"To identify this (woody tissue) we have to rely on three characteristics: (1) the occurrence of pitted tracheids, (2) the presence of medullary rays running at right angles to the tracheids and often containing resin, and (3) the presence of wood parenchyma or cells resembling the rays in form and contents, but parallel to the tracheids".[39]

Smaller structures.

Other structures found are spore exines, cuticle resin, plant fibres, cell remains and mineral grains.

The spore exines or spore coats are formed of resinous and waxy substances and thus are usually well preserved. There are many kinds of spores and from these it may be possible to correlate coal seams.

The cuticle is the epidermis or skin of the leaf or young twigs. This may be detected in both vertical and horizontal section. It usually bears the imprint of the cells which lay underneath it.

Spore exines and cuticle are sometimes hard to differentiate in polished sections as shown by Evans in his statement: [40]

"Cuticle is abundantly evident in thin section of coal though

generally difficult to determine in the etchings ..... The spore case is usually more or less sculptured over its outer surface, and is comparatively smooth inside; while a section of a completely closed cuticle is generally fairly smooth outside but distinctly serrated inside ..... The underlying cells have left their impression on the cuticle which, therefore, if cut by any plane making a fairly large angle with the surface shows a series of small arches on its underside, and when met with as a sheet, although in reality non-cellular, may appear to be of cellular structure owing to the different thicknesses occurring in it".

Resin shows as light-colored globular bodies when seen under the microscope.

Plant fibres will show cell structure. In fact they will be the same as the cell structure already described but in much smaller masses.

C H A P T E R I V.

MICROSTRUCTURE OF ALBERTA COALS.

Geology and Distribution of Coal Types.

Coal is found in Alberta in three horizons, all of Cretaceous age. The coal forming horizons consist of sandstones and shales of continental or brackish water origin, and are separated from one another by marine shales. The stratigraphy of the Cretaceous of Alberta, with the coal-bearing formations emphasized (*), is outlined in the table below.[41]

System	Group	Formation
Upper Cretaceous	Montana	Edmonton* Bearpaw Belly River* Pierre
	Colorado	Benton
	Dakota	Dakota
Lower Cretaceous	Kootenay	Kootenay Coal Measures*

* Coal-bearing formations.

The coals range in grade from lignites to semi-anthracites. Two factors determine the grade of a coal from a given locality, its age as determined by its position in the stratigraphic sequence and the distance the particular locality is from the Rocky Mountains. Generally the grade increases with age, coal from the Kootenay formation usually being of bituminous grade or better wherever found, whilst coal from the Belly

River or Edmonton formation is sub-bituminous or lignite. However, coal of undoubted Kootenay age brought to the surface from deep oil-well drillings in Eastern Alberta has been found to be lignite, and on the other hand, good quality bituminous coal of Belly River age is found within the foothill belt of Southern Alberta, and a great quantity of sub-bituminous coal of Edmonton age is mined in the foothills of Western, Central, and Northern Alberta. Proximity to the mountains with consequent application of pressures developed during the mountain building processes have played a greater part in increasing the grade of the coals than relative age. This perhaps is to be expected in view of the fact that, geologically speaking, there is little difference in the age of the Alberta coals.

Chemical Variations of Alberta Coals.

E. Stansfield[42] has shown that if the moisture and the calorific values for Alberta coals are plotted on a map of Alberta, a striking regularity in the variation of these values is seen. Thus, taking a section across the southern part of Alberta the moisture is found to have a regular variation from 36% in the eastern part to 2% at the western border. The lines of equal moisture are practically parallel to the mountains, i.e. they run roughly from north-west to south-east. In general the calorific value decreases with an increase in moisture. Thus when the calorific values are plotted in the same way they increase from about 6500 B.t.u. per lb. in the east to 13,500 in the west.

These observations show clearly that there are in Alberta coals of all grades from anthracite to lignite. They bring out forcibly the fact that there is no sharp dividing line between coals of various classification but that the gradation from lignite through bituminous coal to anthracite

is a regular continuous series and thus emphasizes the similarity of origin of all coals. Coals, other than special types such as cannels, can vary in degree only, rather than in kind, and hence substances and structures found in one should be directly comparable, with due regard to change due to coal-forming processes, to those found in another. In other words, structure in coal should vary, not with variation in coal types but with variation in the plant tissues and organs from which the coal was formed. As the coalification processes must largely destroy the finer and more detailed structure of the plant tissue leaving only the broad outlines indicative of general types of structure, it should be quite possible to at least use the same terminology in discussing coals of various types.

Previous Studies on the Microstructure of Alberta Coals.

The only investigations, of which the writer is aware, which have been done previously on the microstructure of Alberta coals are an M. Sc. thesis by John McVicar[43] written in 1916. and a Ph.D. thesis written by I.M. Jones at the University of Toronto in 1924.
Mr. McVicar deals rather fully with the methods of accumulation, rates of deposition as applied to the different formations found in Alberta, and to the sections of the Kootanay. Also to the types of organisms of which these accumulations would be composed, the different methods of formation of coal from peat, the factors which affect this formation and the chemical changes which occur during the formation of coal.

In his microscopic work, Mr. McVicar used the thin section method. He describes his method of making microtome sections and also the method of grinding sections. For softening he used hydrofluoric acid and 95% alcohol. The specimens were imbedded both in paraffin and in celloidin. His methods of manipulation of mounting are described in detail. The bleaching was done with Schultz solution or Javel water.

He found difficulty in making ground sections due to the checking caused by rapid loss of moisture. Some experiments were conducted in infiltration with Canada Balsam. He concludes that this is a possible method, but time did not permit him to carry it to conclusion. His method of grinding sections was practically identical with that of Theissen.[44]

Some work was done on maceration, Mr. McVicar found that with treatment with Schultz solution and ammonia, the glanz coal entirely dissolved and the charcoal left a white gelatinous substance. Other samples which were treated longer left only resin.

The coals studied were from mines near the city of Edmonton. McVicar found them to be very similar. His photographs show photomicrographs of woods, fossil woods, and the coals studied.

His conclusions as regards the microstructure of these coals are as follows: "Ordinarily the woody parts are readily recognized through the woody structure itself. The cell walls are distinguishable although the cells have been compressed and reduced to a great degree. The cells are no longer well rounded, with well defined canals, but in most cases flattened out and crushed in. The cells of the spring wood are flattened the most and often appear as a tortuous layer in the more resistant summer wood ..... As the wood itself has suffered a great loss and reduction in metamorphism, the resinous content of the coal appears now very large. Besides showing compression and reduction, the wood shows shifting along the spring wood. It thus must have been in a soft, plastic condition .....

"As seen in cross-section it (spore exine) appears as a compressed or flattened ring, or it may be broken. The wall is generally thin, in color a light yellow with glistening appearance and homogeneous throughout...

"The cutinized membrane of the epidermis can be seen in sections cut crosswise to the bedding .....

"(Resin particles) are always present, being derived from the decayed stems, roots and bark. In the coal sections the resin is often broken out in the cutting or lost on account of its brittleness .....

"[illegible]

* Jones' work was mostly done on coals from the Fernie and Drumheller districts. He tried making thin sections but found that the coals of Alberta were too opaque to make good sections. He concluded that the best method for this coal was that of polished sections, and most of his work was done by that method, using Seyler's method of etching.

Alberta. *

Present Investigation.

The coals chosen for the present investigation are shown in the table below.

Coal No.	Location	Horizon	Classification	A. R. Proximate Analysis				
				Moist. %	Ash %	V. M. %	F. C. %	B.t.u.
1	Anthracite Mine Anthracite	Kootenay	Semi-anthracite	2	12	10	76	13,300
2	Bellevue Mine Bellevue	Kootenay	Bituminous	1	15	30	54	12,800
3	Christie Mine Pincher Creek	Kootenay	Bituminous	3	10	32	55	13,000
4	Coalhurst	Belly River	Sub-bituminous	10	10	34	46	11,100
5	Champion	Edmonton	Lignite	13	7	35	45	10,700

Preparation of Specimens.

The polished section method was used in this investigation because it was decided that more and better results could be obtained in this way in

the time available. The attainment of the technique of this method requires only a few months while that of thin sectioning may require years of practice. It can be seen from the photographs that although the very finer details necessary for a botanical study of a coal may not be shown by this method, the general structures are clearly shown and a very clear comparison between the coals may be drawn.

Many different polishing media were tried and the technique was modified in numerous ways before the methods outlined below were finally adopted.

Polishing.

The specimen was cut with a hack-saw in the desired plane. This face was ground down with three emery cloths of successively finer grades, in such a way that the scratches made by each cloth were at right angles to those made by the previous one. In this way it could be seen when the scratches made by one cloth had been obliterated by the next finer one. Following grinding on the emery papers the surface was polished on a motor-driven, rotating cloth moistened with a suspension of levigated alumina, then on one moistened with red rouge and, finally, on one with water alone. This gave a brilliant, almost scratch-free surface.

Etching.

For etching, Seyler's method was used, but a slightly different technique was found to give better results.

The specimen was first immersed in cold water, which was then gradually heated to boiling. When the specimen was heated throughout, it was transferred to a boiling chrome-sulphuric acid solution. The etching took from one to two minutes. After etching the specimen was replaced in the boiling

water and allowed to cool slowly. When cold it was washed in cold distilled water to remove any traces of etching solution, dried, and then slightly re-polished on a cloth moistened with alcohol.

This procedure, of gradually heating and cooling the specimen previous to and following treatment in the etching solution, greatly reduced cracking and checking of the specimen which otherwise occurred when the cold specimen was immersed in the boiling solution.

Microscopy and Photography.

For microscopic examination and for photography a Lietz Micrometallograph, Model 1924, was employed. This apparatus, equipped with camera attachment and separate eyepiece for visual observations, allowed for careful and rapid examination of all the polished surface and immediate photography of any particular structure. With slight adjustment a wide magnification was available. All magnifications for photographic purposes were measured by a stage micrometer. Eastman $3\frac{1}{4}$ x $4\frac{1}{4}$ Royal Process plates, without color screens, were used for all photographs. These were developed in pyro-soda developer and fixed in chrome-alum hypo solution. All prints were made with Azo F3 papers, developed in Metol-Hydroquinone developer and fixed in a potassium-alum hypo solution.

Description of Coals.

Coal No. 1 is a typical example of semi-anthracite from the Cascade district. This coal is ~~rather friable when mined~~ greatly fractured in the seam but individual pieces are hard and firm. The coal usually carries considerable pyrite and, when stored, the odor of hydrogen sulphide produced from weathering or decomposition of this pyrite is very noticeable.

Macrostructure

Macroexamination of the polished surface (Fig. 1) reveals two

components, anthraxylon and attritus. These form narrow bands of about equal thickness. The hard pyrite particles, breaking out during polishing, make it impossible to produce polished surfaces free from scratches. The narrow banding of the components indicates compression and thus a compact and hard coal.

Microstructure.

Microscopic examination reveals the compart nature of the coal. The bands of anthraxylon show absolutely no structure. The attritus shows traces of structure (Fig. 2) but generally this is so crushed and distorted that determination is impossible. Traces of isolated cells are discernible (Fig. 3) and very rarely, fragments which suggest either the remains of a chip of wood or a very small piece of fusain (Fig. 4). These are the only indications of the possible presence of fusain in this coal.

Coal No. 2 is a bituminous coal from the Crowsnest area.

Macrostructure.

This coal, like the first, is very compact and has a glossy appearance. It is distinctly laminated with bands of anthraxylon and attritus (Fig. 5). The laminae are well cemented and the coal has no tendency to break or crack along the plane of contact. The bands of anthraxylon are quite thick, some being as much as three-eighths of an inch in thickness.

Microstructure.

When etched and examined under high magnification definite structure is revealed, both in the anthraxylon (Figs. 6-7-8) and in the attritus, (Figs. 9 to 19).

The structure in the anthraxylon shows continuous lines indicating

rows of cells and some isolated cells can be seen. The structures suggest woody material greatly compressed and distorted.

The attritus occasionally shows thick-walled smooth-surfaced spores, compressed in most cases until the interior cavity is almost obliterated. Some cuticular tissue is also observable.

Fusain is present to some extent, but is greatly crushed and all structure destroyed. In one case a fair example of "bogen-structure" was detected.

Coal No. 3 is a bituminous coal from the Crowsnest area.

Macrostructure

Macroexamination of the polished face reveals the presence of anthraxylon and attritus together with considerable amounts of fusain. In this coal the anthraxylon bands are wider than those of the attritus (Fig. 20). The coal breaks easily along the lamellar planes due to the presence of fusain.

Microstructure.

The anthraxylon appears structureless even under high magnification. (Fig. 21).

The attritus is not so compact as in the coals described above, but for the most part shows very little definite structure (Figs. 22 and 23).

The fusain is the most interesting component in the coal. In places it is extremely well preserved. (Figs. 24 to 27)

Coal No. 4 is a sub-bituminous coal from the Lethbridge area.

Macrostructure.

This coal is hard but not brittle and has a resinous lustre, and isolated bright, shiny bands can be seen. The coal tends to break along

these bands due to the presence of fusain. The bright bands are usually lenticles about one inch or less long and one-eighth inch to microscopic in thickness. They do not extend throughout the whole area of the coal but are about half an inch in width.

Microstructure.

Under the microscope the coal is seen to have all three components, i.e. anthraxylon, attritus, and fusain. The banded structure is readily seen. The anthraxylon is generally structureless (Fig. 29) and the attritus is so crushed that not much definite structure can be seen. The fusain is very characteristic, showing both well preserved, and crushed, wood-structures (Figs. 33 to 40).

Coal No. 5 is a lignite from the Champion area.

Macrostructure.

This coal is rather friable and tends to split along the lamellar planes. Only two really definite components can be seen; a compact substance which probably corresponds to attritus, and fusain. Small pieces of resin can be picked out of the crushed coal.

Microstructure.

The attritus appears as a granular ground-mass in which very little structure can be seen. In this ground-mass are found occasional cuticular tissues (Fig. 45) and tears of resin (Fig. 44). The fusain is well preserved and shows the structure to great advantage. The cell walls are very thick, almost obliterating the lumens (Fig. 46). They have been greatly compressed.

C O N C L U S I O N S.

Of course it must be seen that in a subject of this nature, where only isolated samples are taken, only very general conclusions can be drawn.

There is fairly distinct evidence that the spore exines of the Kootenay horizon differ from those of the Belly River and Edmonton horizons. The spore exines of the Kootenay, as shown in the Bellevue coal (Fig. 12), are moderately thick walled and smooth, while those of the Belly River and Edmonton are thin walled and spinose (Figs. 31 and 43). These types of spore exines have been described and classified by Slater, Evans, and Eddy.[12]

(Some structures seen in the Christie and Champion coals may be thin walled spores but are more probably vertical sections of cuticle. It is noticeable that spore exines and cuticle are comparatively rare in the Alberta coals.

Another conclusion which might be drawn is that the fusain seems to decrease with the approach of the coal to anthracite. This is probably one of the factors which determine the friability, since coal which contains fusain tends to split along the bedding planes.

In general the anthraxylon appears to be structureless, there being only two instances (Figs. 7 and 30) when this was not true.

Thus it can be seen that, although in general the Alberta coals resemble those ~~of~~ which have been studied in Great Britain and the United States, in certain particulars they are different; spore exines are rarer, cuticle, as far as could be determined, is very rare, resin was only seen in one case. ~~This~~ These differences would be expected, however, since the Alberta coals are Cretaceous, while those studied in Britain and the United States are Palaeozoic.

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Figure 1, Coal No. 1 2.5 X

This vertical section illustrates the narrow, even banding of the coal representing high compression. Anthraxylon (dark) and attritus (light) in narrow bands of about equal thickness. Small white dots in the centre black band are walls of cavities where mineral grains have broken out.

The reversal of light and dark shading in this and other illustrations at low magnifications is due to the use of oblique illumination. The smooth glistening surface of the anthraxylon reflects oblique light at an angle equal to the angle of incidence and thus clear of the microscope, while the less smooth surface of the attritus bands cause some of the light to be thrown or reflected up the barrel of the microscope.

Figure 2. Coal No. 1 100 X

Anthraxylon and attritus. The structureless appearance of the anthraxylon is clearly shown (a). Some isolated cells (b) can be distinguished in the attritus but for the most part it appears as a mass of indistinguishable debris. The dark lines are scratches caused by the breaking out of mineral grains.

Vertical illumination in all photographs at this magnification and higher results in complete reflection of light from smooth, dense portions, such as anthraxylon, giving light colors in the photographs and partial reflection from rough etched surfaces of attritus yielding darker tones.

Figure 1.

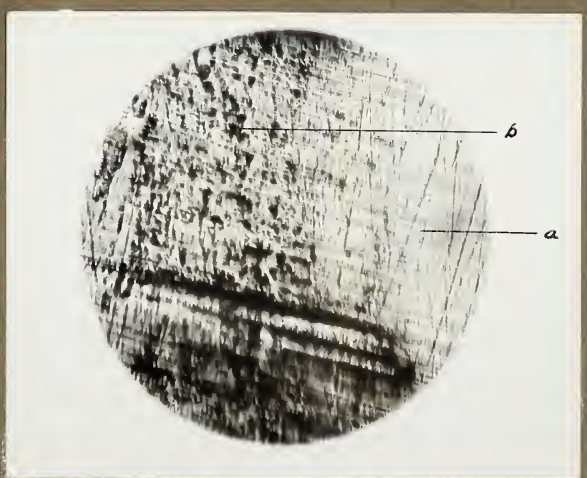

Figure 2.

Figure 3. Coal No. 1 100 X

An area of attritus bounded by structureless anthraxylon and split by a small lens of the same material. Definite structures are not clearly outlined in the attritus, but some vertical rows of cells are visible.

Figure 4. Coal No. 1 100 X

Small fragment showing remnant of woody tissue. The structure is well preserved and the outlines of the cells are clearly distinguishable.

Figure 3.

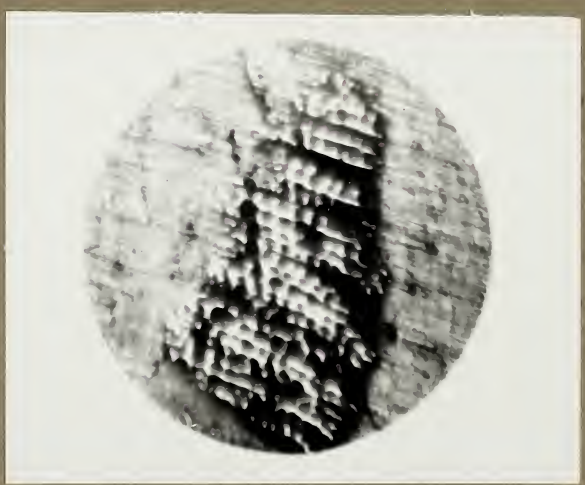

Figure 4.

Figure 5. Coal No. 2. 2.5 X

Block section showing a comparatively narrow band of anthraxylon (dark) between two thicker bands of attritus (light).

Figure 6. Coal No. 2 100 X

Anthraxylon (light) and attritus (dark). If examined closely small dots (a) can be seen in the anthraxylon which probably indicate cell remnants. No definite structures are determinable in the attritus.

Figure 5.

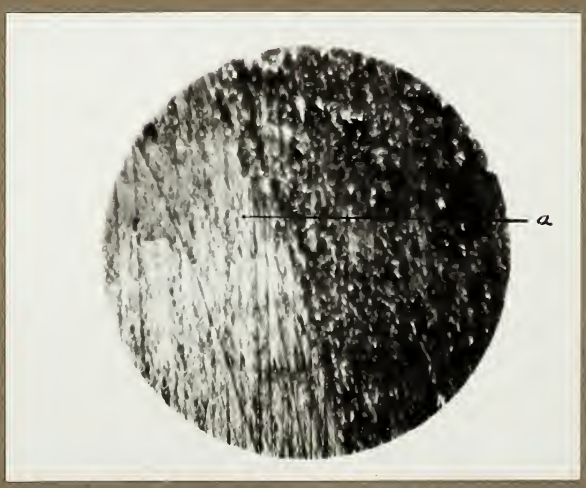

Figure 6.

Figures 7 and 8. Coal No. 2. 500 X

Two illustrations showing structures in anthraxylon. Lines indicating rows of cells are numerous, and in some places isolated cells (a) are visible.

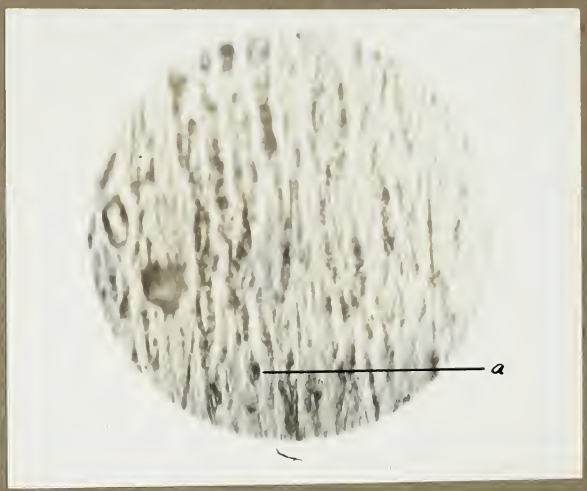

Figure 7.

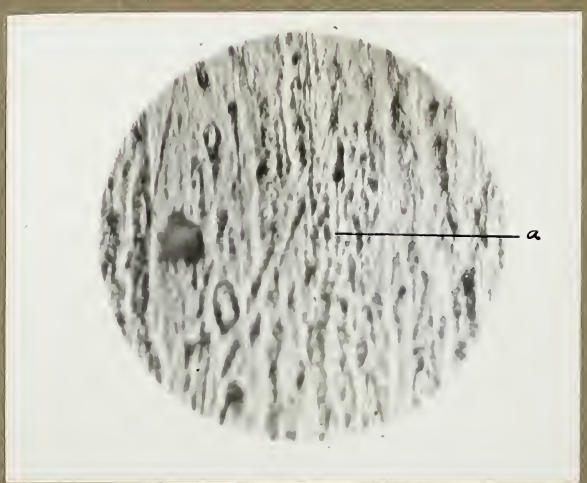

Figure 8.

Figure 9. Coal No. 2 100 X

Vertical section showing isolated cells in attritus. According to Stopes and Wheeler this is caused by premature decay of the middle laminae.

Figure 10. Coal No. 2. 100 X

Vertical section of attritus showing a rather well preserved group of what are possibly tracheids.

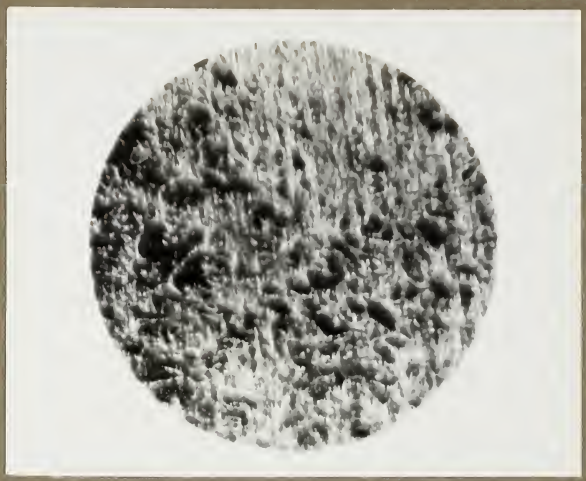

Figure 9.

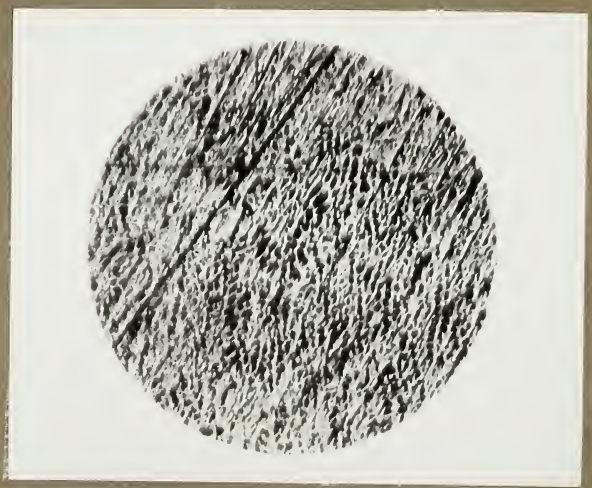

Figure 10.

Figure 11. Coal No. 2. 500 X

Portion of same area as Figure 10 at a higher magnification.

Figure 12. Coal No. 2. 100 X

Vertical section showing a moderately thick walled, amooth surfaced spore-exine (a) imbedded in the attritus. It is noticeable that the crack does not extend through the spore-exine indicating a less friable nature than the rest of the attritus.

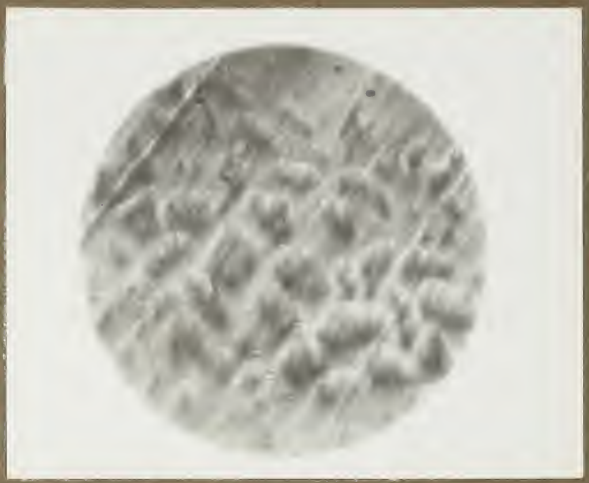

Figure 11.

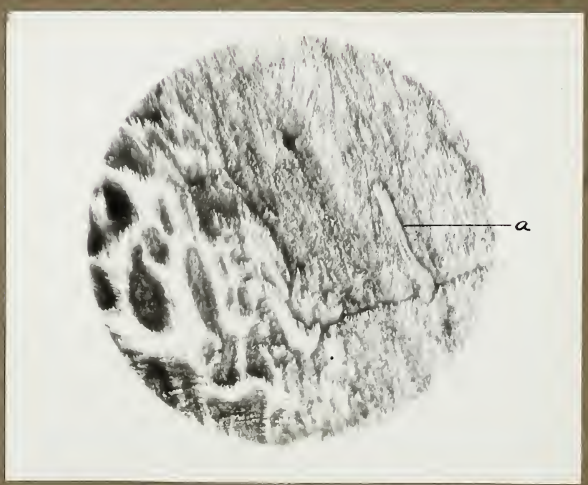

Figure 12.

Figure 13. Coal No. 2. 100 X

A large incomplete megaspore (a) in vertical section. The edges have been corroded and it is impossible to tell whether the outside was smooth or not.

Figure 14. Coal No. 2. 100 X

Vertical section showing woody tissue remnant. The cells are preserved intact in some places (a), but crushed in others (b).

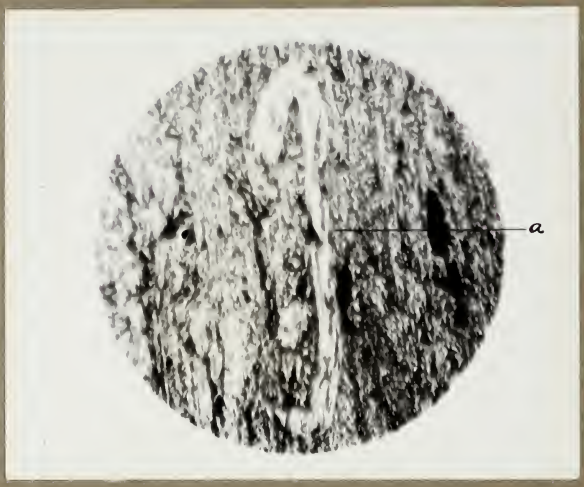

Figure 13.

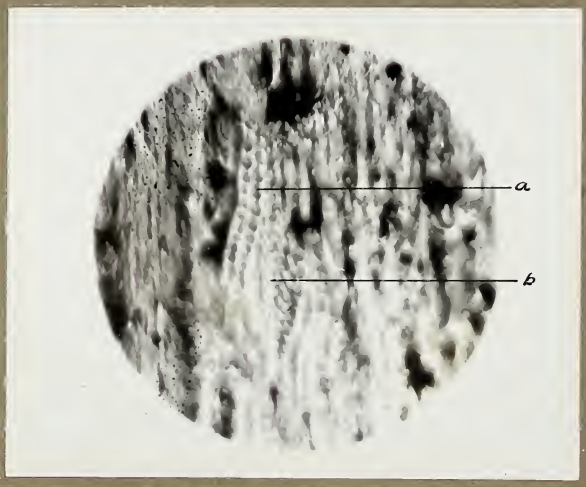

Figure 14.

Figure 15. Coal No. 2. 100 X

Vertical section showing a few preserved wood cells (a).

Figure 16. Coal No. 2. 100 X

Vertical section showing what are probably wedges of fusain (a) in the anthraxylon (b).

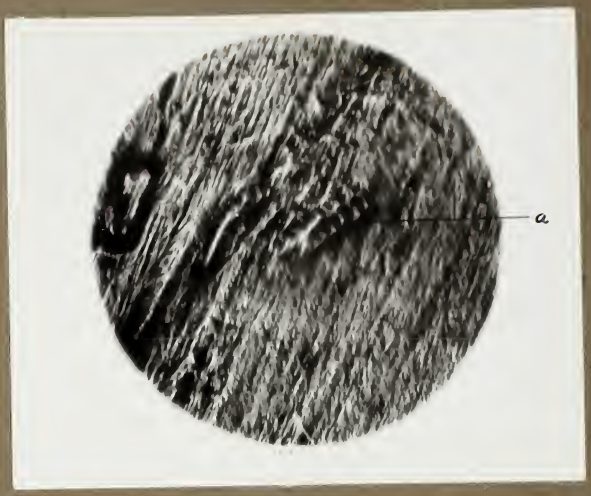

Figure 15

Figure 16.

Figure 17. Coal No. 2 100 X

Horizontal section, showing fairly well developed "bogen-structure". The broken structures grade into a structureless mass.

Figure 18. Coal No. 2. 100 X

Vertical section showing what are probably crushed, fusainized, wood-cells in the attritus.

Figure 17

Figure 18.

Figure 19. Coal No. 2. 100 X

Horizontal section of attritus showing cell remnants (a) lying somewhat obliquely to the plane of the section.

Figure 20. Coal No. 3. 2.5 X

Vertical section showing components. The attritus is rather bright and shows as a darker colored band (a), while the anthraxylon was broken on the surface and shows as light narrow bands (b). This sample was stored in oil, and the oil seeping out caused the black marks around the cracks.

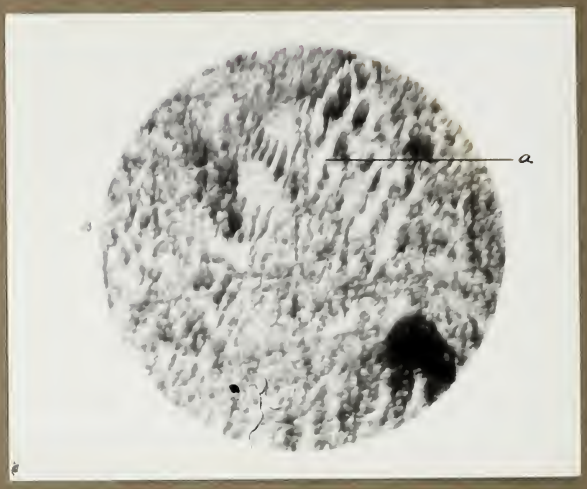

Figure 19.

Figure 20

Figure 21. Coal No. 3. 100 X

Horizontal section showing structureless smooth anthraxylon (a) and rough surfaced fusain (b). The structure in the fusain has been greatly distorted.

Figure 22. Coal No. 3. 100 X

A highly etched horizontal section showing cell remnants. The long white piece is probably a wood fibre but the cells cannot be seen due to the blurring effect caused by the high relief of the section.

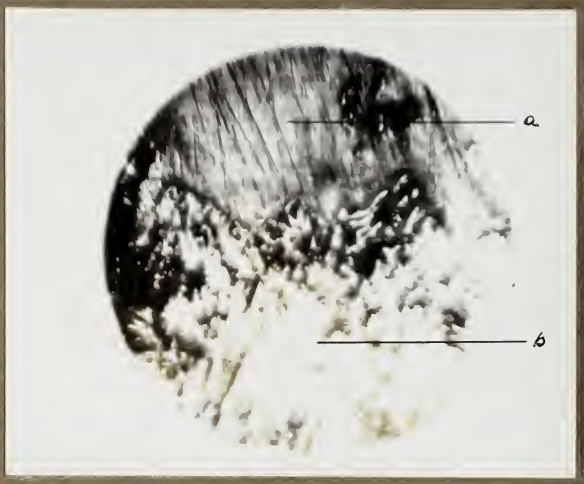

Figure 21.

Figure 22.

Figure 23. Coal No. 3. 100 X

Vertical section showing what is probably a mass of cuticle. An example of closed cuticle is shown apart from the rest (a). Cell impressions are preserved at some points.

Figure 24. Coal No. 3. 100 X

Vertical section of fusain showing rows of cells. Diffusion of the light by the high relief of the surface gives reduced detail and an appearance of being out of focus.

Figure 23.

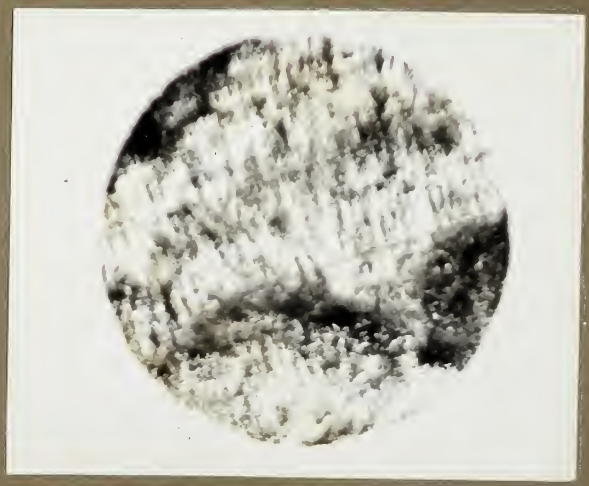

Figure 24.

Figure 25. Coal No. 3. 100 X

Fusain in vertical section showing rows of cells. The black, somewhat irregular line (a) perpendicular to the cell arrangement is possibly the remnants of a medullary ray.

Figure 26. Coal No. 3. 100 X

Vertical section of crushed cells in fusain.

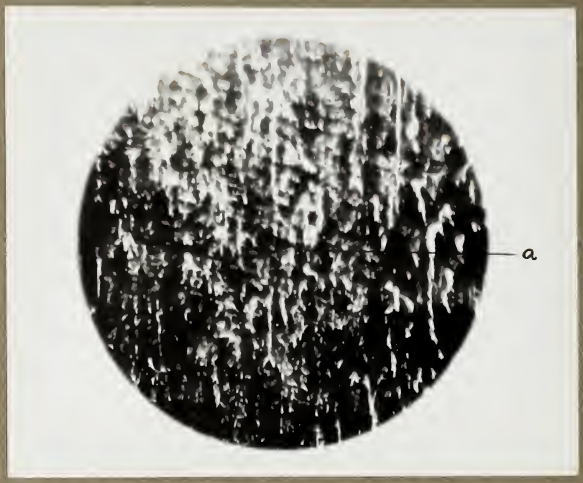

Figure 25.

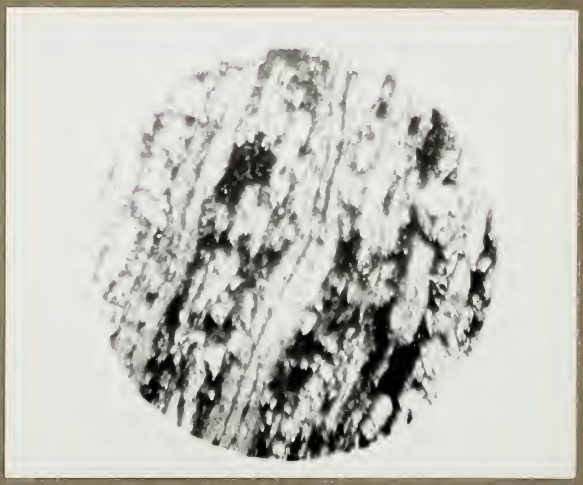

Figure 26.

Figure 27. Coal No. 3. 50 X

Section of fusain. The ~~white~~ lines indicate annual rings brought out by a selective polishing of the spring and summer woods. Traces of medullary rays were seen in this specimen, but they do not show up in the photograph.

Figure 28. Coal No. 4. 2.5 X

Horizontal section showing three components. The light patch in the center is a wedge of fusain. The dark patches are anthraxylon and the grey attritus. Structure can be detected in the fusain.

Figure 27.

Figure 28.

Figure 29. Coal No. 4. 100 X

Horizontal section showing structureless character of the hard, readily polished anthraxylon (a). The pits (b) are caused by the removal of mineral grains in the polishing. Traces of structure can be seen in the attritus (c).

Figure 30. Coal No. 4. 100 X

This specimen was very highly etched as is shown in the attritus where the more resistant portions are left in high relief (a). Traces of cell structure are visible in the anthraxylon (b).

Figure 29.

Figure 30.

Figure 31. Coal No. 4. 100 X

Remnant of what is probably a spore-exine.

Figure 32. Coal No. 4. 100 X

This is probably cork tissue in attritus flattened to lenticular shape by compression.

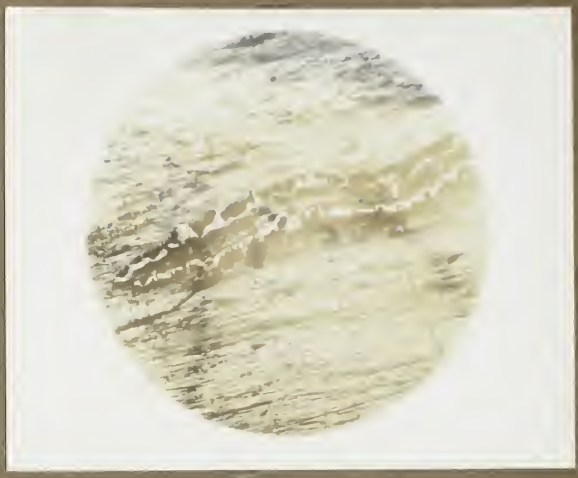

Figure 31.

Figure 32.

Figure 33. Coal No. 4. 100 X

Wood structures, possibly tracheids, occurring in fusain. The structure is not clear enough to distinguish pitting of the tracheids.

Figure 34. Coal No. 4. 500 X

Vertical section of fusain showing two types of cells, honeycomb or hexagonal, and square.

Figure 33.

Figure 34.

Figure 35. Coal No. 4 100 X

A rather poor illustration of a section across a wedge of compressed fusain.

Figure 36. Coal No. 4. 100 X

Crushed wood structures in fusain.

Figure 35.

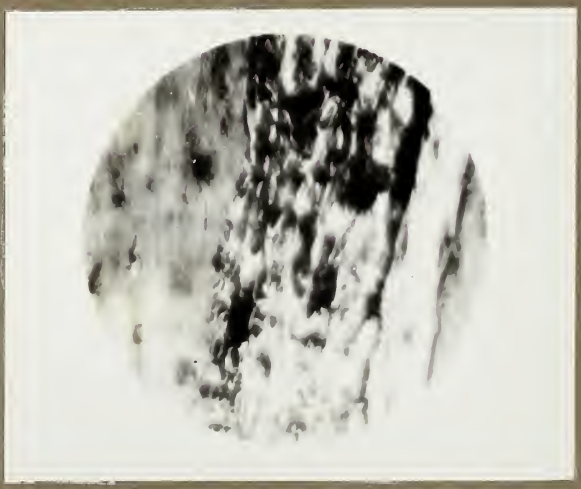

Figure 36.

Figure 37. Coal No. 4. 100 X

Oblique section of thick-walled cells in fusain.

Figure 38. Coal No. 4. 500 X

Cell structures shown in Figure 37 at a higher magnification. Original hexagons considerably distorted.

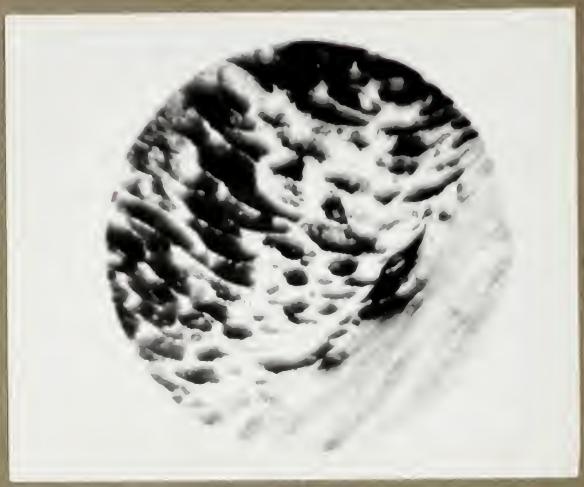

Figure 37.

Figure 38.

Figure 39. Coal No. 4 100 X

Oblique section of fusain showing cells, and anthraxylon.

Figure 40. Coal No. 4. 100 X

Section of compressed fusain. In some places it tends towards "bogen-structure", but for the most part it is too finely divided to show anything but a mass of debris.

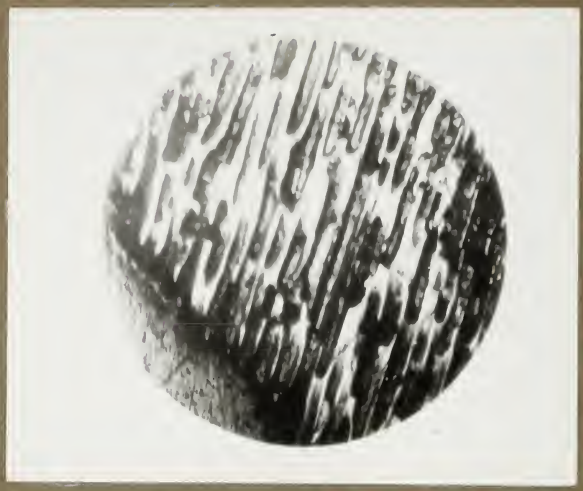

Figure 39.

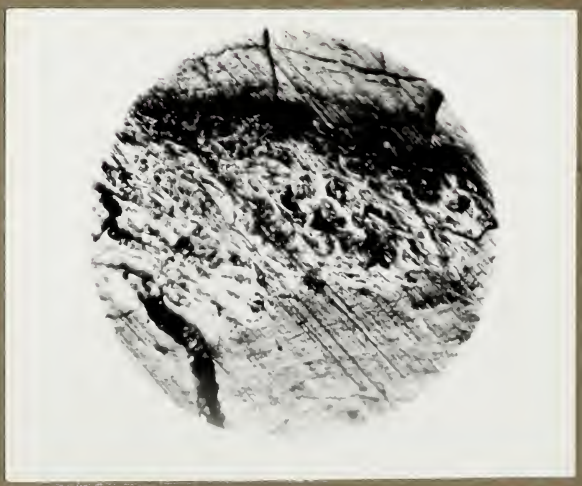

Figure 40.

Figure 41. Coal No. 4. 100 X

This figure shows a very much compressed section of the coal. The anthraxylon (a) appears structureless. The fusain (b) shows traces of cells in places, but in other places it appears to be consolidated.

Figure 42. Coal No. 5. 2.5 X

Vertical section. This coal appears to be a compacted mass made up of lenticular bands of anthraxylon (black) in the attritus.

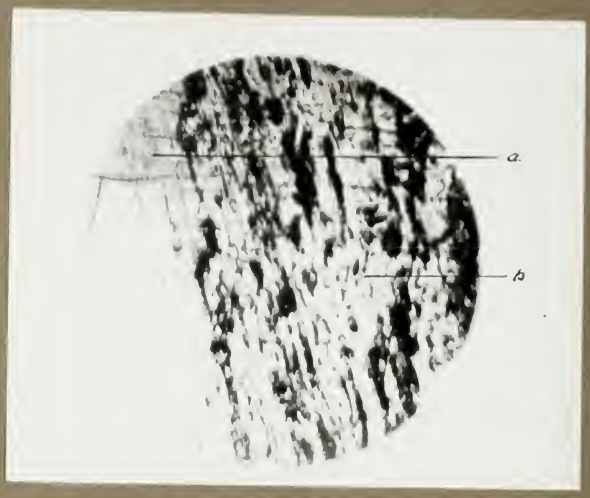

Figure 41.

Figure 42.

Figure 43. Coal No. 5. 100 X

Megaspore exines of the spinose type.

Figure 44. Coal No. 5. 100 X

The small white-colored circular ~~or sub-circular~~ areas represent resin (a). Although the coal contains considerable resin, this was the only indication that was encountered.

Figure 43.

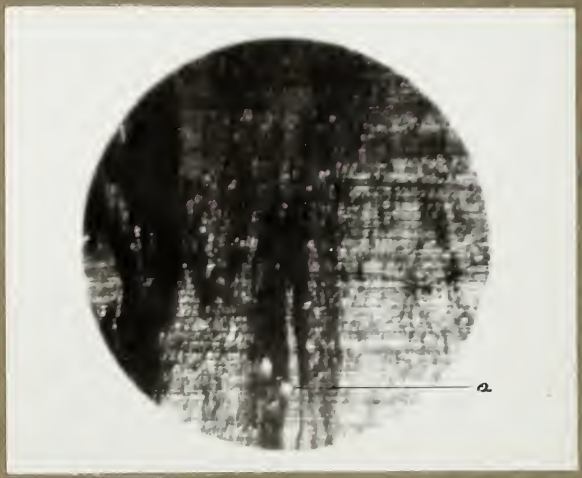

Figure 44.

Figure 45. Coal No. 5. 100 X

Vertical section showing closed cuticle (a). The cell impressions can be seen on the inside edge thus differentiating this structure from a spore exine.

Figure 46. Coal No. 5. 100 X

Wood tissue which has likely been fusainized. The walls are thick and have been compressed so as to obscure the lumens.

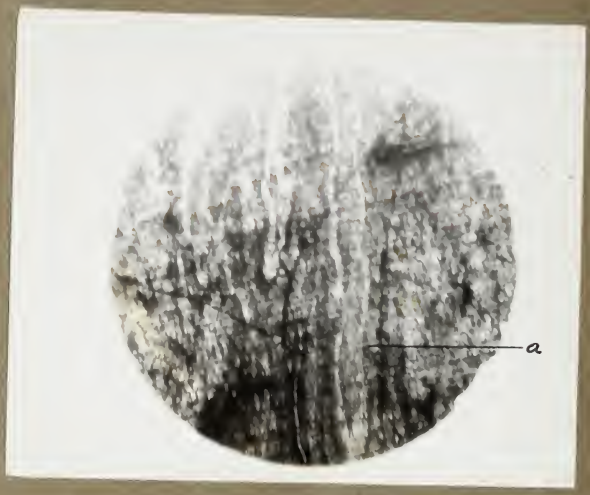

Figure 45.

Figure 46.

Figure 47. Coal No. 5. 100 X

Adjacent area to Figure 46. Compression has not been so great and the lumens, or possible intercellular spaces can be seen at (a).

Figure 48. Coal No. 5. 100 X

Remnants of woody tissue. This structure may be the original structure of the tissue, or it may be caused by distortion. The dark lines are cracks in the section.

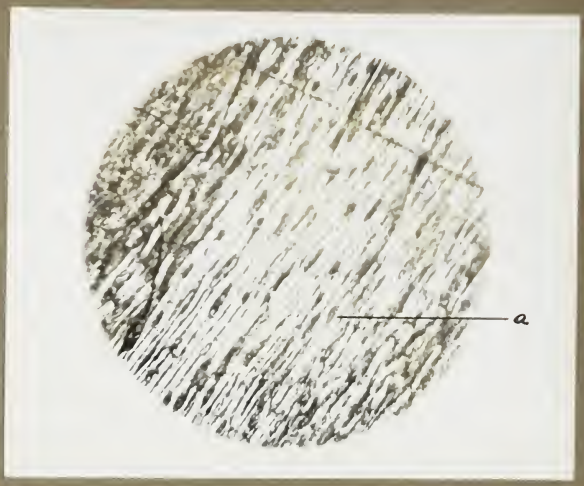

Figure 47.

Figure 48.

Figure 49. Coal No. 5. 100 X

A closely adjacent area to Figure 48, showing the same features.

Figure 49.

B29739